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(54) **Method and apparatus for obtaining physical characteristics of coins for their identification**

(57) Method and apparatus for obtaining physical characteristics of coins for their identification, which consists in submitting the coins to two consecutive stages of electromagnetic measurement, defined by a first and a second pairs of coils, in one of said pairs the coils are connected in such a manner that their magnetic fields are added and in the other in such a way that their magnetic fields are subtracted, which stages providing signals which are processed to obtain parameters representative of the coin, characterised in that the four coils are connected to each other according to a bridge configuration and in that they are supplied simultaneously with at least two, and preferably 3, signals of different frequencies, obtaining simultaneously in each stage, on passage of the coins, two full bridge signals for each frequency and a further two half-bridge signals for the highest frequency, in each case one of the signals being representative of the variation of the resistive component.

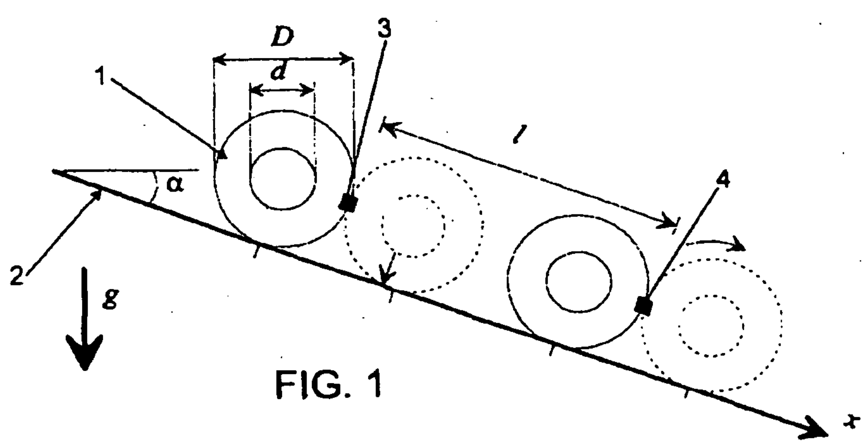

FIG. 1

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Description

[0001] The present invention is related to the methods and apparatus for the verification and validation of coins, both single colour and two-colour; specifically, it refers to a method and an apparatus for obtaining the physical characteristics of coins for their identification and subsequent validation and/or rejection.

Background of the invention

[0002] The methods and apparatus for verification of coins in those in which a coin is subjected to an alternating magnetic field generated by inductive coils are well known. The coin produces a determined variation of the magnetic field depending on the field frequency, the coin dimensions, the spacing between the coin and the coil and the electrical properties (electrical conductivity and magnetic permeability) of the metal of the coin. The size of the inductive sensors is habitually comparable with that of the coin in order to ensure sufficient sensitivity. Large sensors tend to respond to the overall properties of the coins. It is for this reason that with these sensors it is not possible to identify easily the two-colour coins which have and internal disc surrounded by an external ring, in which the disc has electromagnetic properties different to those of the external ring. Likewise, the measurement of the diameter of the coin and, in particular, of the diameter of the internal disc of the two-colour coins proves difficult with large coils. The sensor coils are connected, habitually, to a self-oscillating circuit and the changes undergone in the oscillation amplitude caused by the coin are measured and used in the verification of the coin. In this configuration, an inductive coil measures only at a single frequency and an independent circuit is necessary for each inductive coil. This implies that the electronic system has to be more complicated and costly. Moreover, the self-oscillating circuits are liable to age and tend to show thermal drift and need to be calibrated often. No satisfactory system has been designed to resolve the problem produced by the dependence which the signal has on the distance separating the coin and the coil. This problem is mitigated if the coin passes through a narrow passageway between two coils, but it still remains.

[0003] For the verification and validation of coins, a diversity of apparatus and methods are already known, based on the principles expressed above, among which are:

[0004] The United States' patent US-3870137-A which describes a method and apparatus for examining coins by submitting them to two magnetic fields at two frequencies, which are produced by independent inductances. In this patent only the change of the coil inductance is measured.

[0005] The United States' patent US-4754862-A which describes an apparatus for discriminating coins in which the detectors comprises three coils, each one of which is mounted in a parallel L-C resonant circuit. The resonant circuits are activated sequentially by a voltage-controlled oscillator VCO by means of a multiplexer; the VCO is synchronised in phase to any of the three L-C circuits to which it is connected via a phase comparator and a feedback circuit. The resonant frequency and the amplitude are digitised; their values depend on the coin parameters. The method of detection presented in this patent has various drawbacks: the phase synchronisation requires tuning and its implementation is costly; the resonant circuits are prone to ageing and tend to show thermal drift and, as a consequence, require calibration frequently; moreover, the sequential monitoring of the phase-synchronised L-C circuits is slow.

[0006] The patent application PCT n° publ. WO 93/02431 describes a method for a coin verification apparatus in which the coins are made to pass through a magnetic detection field, produced by a single coil to which is applied simultaneously one high frequency and two low frequency signals. The apparatus has a receiving coil connected in series with an auxiliary receiving coil. A transmitter-receiver set-up is employed. The attenuation of the field is measured from the transmitting coil to the receiving coil caused by the coin and it is used for verification of the coil, but the measured attenuation is not clearly specified; moreover, the amplitude attenuation of an alternating magnetic field is not a very sensitive method.

[0007] The patent application PCT n° publ. WO 93/21608 describes a method for coin verification in an oscillating field of a single coil by measuring the influence of the coin on the coil impedance. The verification is based on measuring the direction of the impedance plane of a displacement line which represents the displacement of the point at which the coin is present with respect to a point where the coin is not present and in the determination of whether this direction corresponds with a reference direction. The object of this method is the verification of coins in a manner which is not sensitive to the distance separating the coin and the sensor. The reactive and resistive components of a single sensor are measured either through the use of a freely running oscillator or by means of a phase detection method.

[0008] The patent application PCT n° publ. WO 93/22747 describes a coin validator which has a sensor circuit which includes two sensor coils, which are positioned in such a manner that the coin which runs along the channel passes by them in succession. Electrically the coils are connected in a bridge circuit, the second arm of which is comprised of reference resistances. The two coils on the same side of the coin, hence the signals are heavily dependent on the lateral separation existing between the coil and the coin. Secondly, the resistances that are employed as reference in the bridge generate thermal noise which finally delimits the signal to noise ratio. Thirdly, the detector circuit cannot measure separately the reactive and resistive components in the coil impedance, of a signal which is a certain com-

bination of these components. This severely limits the coin identification capability of the method.

[0009] The United States' patent US-5337877-A presents a method which measures the thickness of the coin. Two coils lodged one on each side of the coin passage comprise the sensor; two frequencies are independent oscillators are employed for each of the coils. The outputs from the coils are processed separately in order to obtain values which are combined in order to provide an indication of the thickness of the coin. Each output is processed separately by using a transformation table to obtain the thickness, which requires many calibration readings.

[0010] The application for European patent n° publ. EP-0724237-A2 describes a method for classification of coins by means of two pairs of sensor coils situated on the right and left of the channel, which comprise internal and external coils for the reduction in size of the coin classification machine. The internal and external coils are connected in a different manner: one of the connections is differential whilst the other is additive. The internal and external coils are, each of them, connected to an oscillating circuit; the oscillating frequencies are such that one of them is greater than twice the other.

[0011] The application for European patent n° publ. EP-0805423-A2 describes a method for verification of coins or other metallic elements based on the use of a coil, which is fed simultaneously from two voltage or current sources at different frequencies; the coil is coupled to the sources with capacitors, with which it forms the impedances Z1 and Z2. The verification of the coins is based on measuring the difference in phase between the voltage across the impedances Z1 and Z2 and the pertinent source voltages. This patent has a serious drawback: the phase difference depends on the resistance of the coils and on their coupling capacitance, both of which are sensitive to temperature change and to ageing which cause drift.

[0012] The United States' patent US-5687830-A describes a method and apparatus which consists of a two-coil system. The dimensions of the coil system exceed the diameter of the largest acceptable coin. The coils are operating in two independent L-C circuits oscillating at frequencies of 120 kHz and 2 MHz, that is, each functional coil system at a single frequency. The method discriminates between an acceptable and an unacceptable coin through the measurement of six characteristics: two oscillation frequencies, two signals related with the amplitude of oscillation and the variation with time of the last two signals. The drift inherent in all self-oscillating detection systems is offset by means of automated calibration. These six characteristics do not permit an accurate measurement of the outside diameter of the coin or of the inside diameter of the outside ring of a two-colour coin.

[0013] The application for patent PCT n° publ. WO 98/37522 describes a method for validation of two-colour coins. An oval-shaped sensor is employed for measuring the type of material that constitutes the outside ring of a two-colour coin and of the coin diameter. An independent coil is employed, mounted inside the oval sensor, for measuring the thickness and the type of material of the coin. The two-coil systems are situated in two independent self-excited oscillators. The frequency and amplitude of oscillation are measured.

Description of the invention

[0014] The object of the present invention is a method and a multi-frequency apparatus for the identification of coins, by means of which it is possible to perform the measurement of the following parameters of the coins: outside diameter, inside diameter of the concentric ring of bimetal coins, total thickness, presence of an internal magnetic layer, and a set of parameters for the identification of the metallic alloys in the coin, or of each part of the coin, centre and ring, in the case of two-colour coins. The method of the invention is based on measuring the impedance of inductive coils at, at least, two frequencies, by employing four coils of reduced dimensions in a bridge configuration.

[0015] An object of the invention is to achieve an apparatus in which the same voltage is applied to the four coils, which are in a bridge configuration, and each of said coils is simultaneously controlled with, at least, two different frequencies. In the present invention use is made of only one generator and from its signal, at least two measuring frequencies are obtained.

[0016] The impedance of the coils is measured, and the detection sensitive to the change in phase of the impedance of the coil in a bridge, employed in the present invention, offer a signal to noise ratio and an immunity to greater external disturbances.

[0017] The present invention proposes a simple new method based on a four-coil bridge which measures the real distance separating the coin and the coil, and which employs the result of said measurement to offset the effect that the separation has on the measured values of the impedance change.

[0018] The coils of reduced dimensions employed in the present invention are capable also of detecting the concentric ring of a two-colour coin.

[0019] Specifically, the invention refers to a method of obtaining physical characteristics of coins for their identification, which consists in subjecting the coins to two consecutive stages of electromagnetic measurement, defined by a first and a second pair of coils, in one of said pairs the coils are connected in such a manner that their magnetic fields are added and in the other pair the coils are connected in such a manner that their magnetic fields are subtracted; these stages of electromagnetic measurement provide signals which are processed in order to obtain parameters

representative of the coins. The four coils are connected to each other in a bridge configuration. The two pairs of coils that constitute the bridge are supplied simultaneously with at least two, and preferably three signals of different frequencies, being obtained simultaneously on the passage of the coins, two signals from the full bridge for each frequency and another two signals from the half-bridge for the highest frequency, in each case one of the signals being representative of the variation in the inductive component and the other representative of the variation in the resistive component.

[0020] The two pairs of coils that constitute the bridge are supplied simultaneously with, at least, two and preferably three, signals at frequencies situated in clearly different bands, that of low frequency being a few kHz, preferable around 2.5 kHz, that of high frequency being about 1 MHz or higher, preferably around 1.2 MHz, and the frequency of the third signal to be a few tens of kHz, preferably around 75 kHz.

[0021] For the purpose of obtaining the correct variations in impedance, both of the inductive component and of the resistive component, the method incorporates a calibration in which the measurement is carried out with a disc fabricated from low-loss ferrite; this disc has the property of producing a change of the inductive part in the coils whilst the change in the resistive part remains negligible. The correct changes in the resistive and inductive part are obtained from the measurements of voltage changes of the full bridge making use of the equations:

$$\Delta V'_r = \cos(\beta)\cdot\Delta V_r - \sin(\beta)\cdot\Delta V_i$$

$$\Delta V'_i = \cos(\beta)\cdot\Delta V_i - \sin(\beta)\cdot\Delta V_r$$

$$\Delta L = \frac{-2}{V}\left(\frac{R\cdot\Delta'_i + X\cdot\Delta'_r}{\omega}\right)$$

$$\Delta R = \frac{2}{V}(X\cdot\Delta V'_i - R\cdot\Delta V'_r)$$

where β is the angle of rotation of the system of coordinates in the impedance plane, ΔV_i and ΔV_r are the changes in the imaginary and real parts, respectively, of the output voltage of the full bridge, ΔL and ΔR are the variations in the inductive and resistive component, respectively, of the coil, V is the supply voltage of the full bridge and R and X are the resistance and reactance of the of the coil uninfluenced by a coin.

[0022] The calibration is carried out by seeking an angle β for each of the frequencies, which gives a variation in the resistive component equal to zero.

[0023] To obtain optimal signals from the first and second pairs of coils, the coins must pass as uniformly as possible in regard to the relative separation of the coin with respect to the side walls on which are mounted said pairs of coils. In practice the coins do not meet this requirement and their passage along a measurement channel in which the two pairs of coils are mounted, is altered by a lateral displacement with respect to the ideal trajectory. Said displacement, known as "lift-off" and which is unpredictable, affects the measurements and impairs the accuracy of the readings taken, which in the coin identification phase can signify rejection of valid coins or acceptance of counterfeit ones. Further below an explication shall be given of a procedure to counteract this occurrence.

[0024] The measurement of the thickness T of a coin is based on the fact that the variation in the inductive component at the highest frequency f_k is related principally with the distance between the face of the coin and the coil.

[0025] The following model is established:

$$\Delta L_{kD} = \frac{A}{(s_1)^{N}}$$

$$\Delta L_k = \frac{A}{(s_1)^N} + \frac{A}{(s_2)^N}$$

where s_1 and s_2 are the separations between the two coils which add their magnetic fields and the face of the coin, N>0 a parameter and A another parameter, both obtained by calibration, ΔL_k the signal of the variation in the inductive component in the full bridge at the highest frequency f_k in the stage defined by the coils which add their fields, and

ΔL_{kD} the signal of the variation in the inductive component in the half-bridge at the highest frequency f_k in the stage defined by the coils which add their fields.

[0026] Using the model given, the thickness T of a coin is calculated from the expression:

$$T = e - \sqrt[N]{\frac{A}{\Delta L_{kD}}} - \sqrt[N]{\frac{A}{\Delta L_k - \Delta L_{kD}}}$$

where e is the distance separating the two coils in which their fields are added.

[0027] The parameter A is determined by calibration for a coin with a known thickness T, measuring ΔL_k and ΔL_{kD} and applying the expression:

$$A = \left[\frac{e - T}{\frac{1}{(\Delta L_k - \Delta L_{kD})^{1/N}} + \frac{1}{(\Delta L_{kD})^{1/N}}} \right]^N$$

[0028] It shall be necessary to calibrate the parameter A separately for each kind of alloy, since at the highest frequency f_k employed the variation in the inductive component depends of the conductivity and on the magnetic permeability of the alloy the coin is composed of.

[0029] When the given model is employed, a value should first be found that is suitable for the thickness N with a given distance e. This can be encountered by measuring each coin with different lift-offs and calculating the parameter A for each lift-off; a correct N is obtained when A is equal for each one of the measurements. It is not necessary to repeat this procedure for each of the arrangements set up for the two pairs of coils, it being sufficient to find a correct N for each arrangement.

[0030] It is also possible to calibrate the parameters A and N applying a least squares adjustment to the signals $\Delta L_k(T_j)$ and $\Delta L_{kD}(T_j)$ at the highest frequency f_k measured in coins or discs specially fabricated with different thicknesses T_j and different lift-offs. The thicknesses of the discs are known. The two parameters are found by finding the minimum from

$$\min\left\{ \sum_{i,j} \left(T_j - e + \sqrt[N]{\frac{A}{\Delta L_{kD}(T_j)}} + \sqrt[N]{\frac{A}{\Delta L_K(T_j) - \Delta L_{kD}(T_j)}} \right)^2 \right\}$$

[0031] The sum examines all the measurements *i* and thicknesses *j*. Well known numerical algorithms are employed for adjusting the non-linear function. This multi-parameter model offers a systematic approximation for modelling and extracting the thickness.

[0032] It is also possible to calculate the thickness T of a coin by establishing a polynomial approximation of order n to the theoretical curve which relates the variations in inductive component of the coils and the coil-coin distances as per the expressions:

$$s_1 = a_0 \Delta L_{kD}^n + a_1 \Delta L_{kD}^{n-1} + \Lambda + a_n$$

$$s_2 = b_0(\Delta L_k - \Delta L_{kD})^n + b_1(\Delta L_k - \Delta L_{kD})^{n-1} + \Lambda + b_n$$

where s_1 and s_2 were defined above, a0, a1, ... an and b0., b1, ... bn are coefficients determined by calibration, ΔL_k the signal of the variation in the inductive component in the full bridge at the highest frequency f_k in the stage defined by the coils which add their fields, and ΔL_{kD} the signal of the variation in the inductive component in the half bridge at the highest frequency f_k in the stage defined by the coils which add their fields.

[0033] From s_1 and s_2 the thickness T of the coin is calculated according to the following expression:

$$T = e \cdot (s_1 + s_2).$$

[0034] There are sufficient fourth order polynomials for a correct approximation.

[0035] The variation of the inductive component in the full bridge ΔL_k at the highest frequency f_k is mainly independent of the electrical properties of the coin. For this reason ΔL_k is adequate for determining the outside dimensions of the coin. However, for measuring the diameter d of the centre of two-colour coins, it is necessary to use a signal of the variation of the inductive component at a lower frequency, for the purpose of distinguishing between the different metals.

[0036] Next a method is present for calculating the diameters from said signals. The method is based on the fact that there is a change in the inductive component at the time at which the edge of a coin runs passes between the coils; this change is utilised for time measuring purposes.

[0037] The parameter t is considered to be equal to zero at the instant at which the front edge of the coin, or of the centre for two-colour coins, penetrates between the first pair of coils, t_1 the instant at which the rear edge of the coin, or of the centre for two-colour coins, exits from between this first pair of coils and t_2 and t_3 the instants at which the front and rear edges of the coin, or of the centre of two-colour coins, enters and exits, respectively between the second pair of coils, and l the distance between the second pair of coils.

[0038] When the coin runs down a ramp with a velocity v from a point x=0 at point x, the potential energy $mgx\sin\alpha$ is transformed into rotational and kinetic energy, and into heat due to friction. The acceleration due to gravity is g. It is assumed the frictional work is proportional to the mass m, to g and the the distance times the distance x travelled. This model implies that the force of friction is more or less proportional to the velocity. But this model would lead to a transcendental equation which would require a numerical solution. The approximation proposed is sufficiently good if the velocity does not increase substantially when the coin rolls down the ramp. The following energy relationship is obtained:

$$mgx \sin \alpha + \frac{1}{2}mv_0^2 + \frac{1}{2}I\omega_0^2 = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + \eta mgx \qquad (1)$$

Where m is the mass of the coin, α is the angle of inclination of the ramp, v_0 is the velocity at t=0, I is the moment of inertia of the coin, ω_0 is the angular velocity at t=0 and η is the coefficient of friction. It is furthermore considered that the coin is a homogeneous disc of diameter D. In this case, it is considered that $\tau=1/2m(D/2)^2$ and that $\omega=2v/D$. Given that $v=dx/dt$, equation (1) gives a solution for x, as a function of time t:

$$x(t) = v_0 t + \frac{1}{3}gt^2 (\sin \alpha - \eta)$$

[0039] Where l is the separation between the first and the second pair of coils, it is possible to express a series of three linear equations: $x(t_1)=D$, $x(t_2)=l$, and $x(t_3)=l+D$. The unknowns are v_0, η and D.

[0040] Thus the diameter D of a coin, or the diameter d of the centre in the case of a two-colour coin, can be calculated using the expression:

$$D = \frac{t_1[t_3(t_1-t_3)-t_2(t_1-t_2)]}{t_2(t_1-t_3)(t_1-t_2+t_3)} l \qquad (2)$$

[0041] The distance l acts as a master length for measuring the diameter. The times t_1, t_2 and t_3, are determined by calculating the derivative of the signal of the variation of the inductive component in the full bridge, at the highest frequency for single colour coins, and for two-colour coins, at the lowest frequency in the case of using the pair of coils in which their fields are subtracted, and at the intermediate frequency in the case of using the pair of coils in which their fields are added. The passage of the edges generates different maxima and minima in the derivative of the signal of the variation of the inductive component in the full bridge which are those which provide the timing instants, by adapting parabolas on said maxima and minima.

[0042] The diameter d of the centre of a two-colour coin can be calculated also from the signal measured, but it is necessary to know the other two unknowns v_0 and η. From the linear equations mentioned above, one obtains:

$$\eta = \frac{3}{g(t_1 - t_2)}\left(\frac{l}{t_2} - \frac{D}{t_1}\right) + \sin\alpha \qquad (3)$$

where has been obtained from the equation (2): In like manner, one obtains the initial velocity:

$$v_0 = \frac{l}{t_2} - \frac{1}{3} g t_2 (\sin\alpha - \eta)$$

where η is obtained first from equation (3). Next, it is possible to calculate the diameter d of the centre from the equation:

$$d = (t_5 - t_4)\left[v_0 + \frac{1}{3} g (t_5 + t_4)(\sin\alpha - \eta)\right] \qquad (4)$$

where t_4 and t_5 are the instants at which the entry and exit, respectively of the centre of the two-colour coin are detected in one of the two measuring stages, the signal of variation of the inductive component at the lowest being used in the case of using the pair of coils in which their fields are subtracted, and the signal of variation of the inductive component at the intermediate being used in the case of using the pair of coils in which their fields are added.

[0043] As already mentioned, the displacement known as lift-off is not predictable and affects the readings and impairs the accuracy of the measurements made, which in the coin identification phase lead to rejection of valid coins or acceptance of counterfeit ones.

[0044] The procedure proposed hereunder permits the offsetting to a large extent of the errors introduced by the irregular passage of the coin along the measurement channel, thereby improving the acceptance quality and the discrimination of counterfeits.

[0045] The coils measure the coins on both faces. It is to be expected that the voltage amplitude of the full bridge due to the coin be less for equal coil-coin separations, that is, when $s_1 = s_2$, and that it be greater when the coin is closer to either of the coils. For a trustworthy identification of the coin, the lift-off dependency has to be offset. The variation in the inductive component ΔL_k at the highest frequency depends firstly on the distance from the coil to the surface of the coin. This permits the definition of a number of parameters that ought to be virtually independent of the lateral position or lift-off of the coin with respect to the coils, and which are representative of the electromagnetic characteristics of the coins. These parameters are the non-dimensional values $r_1 = \Delta R_1/(\omega_k \Delta L_k)$, $r_2 = \Delta R_2/(\omega_k \Delta L_k)$, $r_l = \Delta R_l/(\omega_k \Delta L_k)$, $l_1 = \Delta L_1/\Delta L_k$, $l_2 = \Delta L_2/\Delta L_k$, $l_l = \Delta L_l/\Delta L_k$, where ΔR_1, ΔR_2, Δr_l, ΔL_1, ΔL_2, ΔL_l are variations in the resistive component and in the inductive component in the full bridge on the passage of the coins through either of the two measuring stages, for each frequency f =1, 2, ...l, ...k, $\omega_k = 2\pi f_k$ where f_k is the maximum working frequency.

[0046] When these parameters are employed for the identification of coins, the lift-off of the coin is mainly offset.

[0047] The procedures for determining the geometrical dimensions of the coin, the outside diameter, the diameter of the inside concentric ring and the total thickness of the coin, take lift-off into account. The method employed in determining the diameter is virtually independent of the lift-off as is explained hereunder: The method is based on the timing series of the data points $\Delta\Delta L$. This is an estimate of the derivative with respect to time of the signal ΔL and is obtained by calculating the difference of the consecutive ΔL data points. Although the amplitude of $\Delta\Delta L$ depends on the lift-off, the same does not occur with the positions of the maxima and the minima in $\Delta\Delta L$. The method for determining the diameter is based on the use of these terms as time signals for the equations (2) or (4).

[0048] The invention likewise refers to an apparatus for obtaining physical characteristics of coins for their identification, which comprises two pairs of inductive coils, the coils in each pair being disposed in a facing manner, situated on opposite sides of a ramp along which the coin runs, at the same height with respect to said ramp. The four coils are connected in a bridge configuration, the facing coils of each pair being connected to opposing arms of the bridge and in such a manner that in one of the pairs of coils their magnetic fields are added, whilst in the other they are subtracted, all the coils being supplied simultaneously from a generator which provides at least two first signals at different frequencies which feed the bridge, and at least, two second signals, 90 degrees out of phase with respect to the first signals.

[0049] The apparatus additionally comprises synchronous demodulators to extract at each of the frequencies, the variations experienced in each one of the two measuring stages during the passage of the coin, using the first signals to obtain the variations in the resistive component, and using the second signals, to obtain the variations in the inductive component.

[0050] The diameters of the coils ought to be less than the diameter of the coin or, in the event of a two-colour coin, of the radial extension of the ring.

[0051] In the present invention, the properties of the four-coil bridge are used in many ways. The bridge is fed in bipolar fashion (amplifiers with gains of +1 and -1) in order to reduce the common mode signal at the input of the amplifiers and, also, to maintain the electrical balance of the bridge with respect to its environment. This means that

it is very resistant to external disturbance. In a balanced bridge, the alternating output voltage of the full bridge is zero. It is also virtually independent of thermal drift if the coils in the bridge are identical and if they are at the same temperature. This is, in practice, the case of coin validators. Because the reading is made using an alternating voltage, the system is also independent of amplifier offset drift. The amplifier gain is determined by the ratio of the resistors and is, as a consequence, also independent of temperature.

[0052] The operation of the method and apparatus of the present invention is as follows. When a coins rolls down the inlet ramp, it first runs past a first pair of coils; the inductive component and the resistive component of these coils vary and, since the other pair of coils of the other arm of the bridge does not vary, at least during a part of the time that the coin is passing, the bridge is out of balance. Alternating voltages appear on the full bridge and on the half bridge. These changes in alternating voltage depend strongly on the lift-off of the coin between the coils, and permits, in this way, the measurement of said lift-off. The voltage changes depend on the frequency and on the coin alloy. Since the coils are reduced in size, the changes in voltage indicate the spatial distribution of the different metals in the coin. The signals that are obtained from the two pairs of coils can be employed either directly or with offsetting of the lift-off for validating the coin in motion by techniques already known. It is also possible to employ in the identification process the diameter and thickness calculations.

[0053] The essential point of the present invention is the fact that the four detector coils of reduced size are in a bridge configuration and that the two pairs of coils that comprise the bridge are supplied simultaneously with at least, two signals and preferably, three signals at different frequencies. Since each coil acts as a sensor, and since there are no resistive components in the bridge, this system permits the maximum signal to noise ratio to be reached, said ratio being limited by the resistive loss due to the coin.

[0054] A fuller description of the invention is now given, with the assistance of the drawings appended, which are related expressly to an embodiment of said invention which is presented by way of an illustrative example of the invention and not restrictively.

Brief description of the drawings

[0055]

Figure 1 is a schematic view of the inlet ramp and of the two pairs of detector coils of an apparatus for obtaining the physical characteristics of coins according to a preferred embodiment of the invention.

Figure 2 is a plan view of the part of the apparatus shown in figure 1.

Figure 3 shows the simplified schematic of the electronics of the apparatus of the invention.

Figures 4 to 11 show an example of the signals that are obtained with the method and apparatus of the invention for a brass coin with a diameter of 24.75 mm.

Figure 12 shows the derivative of the signal dL at the one frequency of 1.25 MHz of figure 6 multiplied by 15, that is, $15*\Delta\Delta L$.

Figure 13 shows the result of a reading obtained with the present invention for a two-colour coin with Magnimat centre.

Figures 14 and 15 show the signals obtained with the method and apparatus of the invention for a British copper-coated one penny piece.

Figures 16 and 17 show the signals for a British copper-coated one penny piece with the copper coating removed.

Figures 18 and 19 show the signals obtained with the method and apparatus of the invention for a German five-mark piece, 5DEM.

Figures 20 and 21 show the signals obtained with the method and apparatus of the invention for a British ten-penny piece.

Figures 22 and 23 show the signals obtained with the method and apparatus of the invention for French five-franc piece, 5FF.

Figures 24 and 25 show the signals obtained with the method and apparatus of the invention for a Swedish ten-crown piece, 10SEK.

Figures 26 and 27 show the signals obtained with the method and apparatus of the invention for a two-colour coin with Magnimat centre, slightly magnetic whilst the ring is non-magnetic.

Description of an embodiment of the invention

[0056] Figure 1 is a schematic view of a coin 1 on an inlet ramp 2 and of one of the coils of a first pair of coils 3-3' and of one of the coils of the second pair of coils 4-4',. In the side elevation of the constructed ramp 2, in a first configuration, it is seen that the distance l between the first pair of coils 3-3' and the second pair of coils 4-4' over the length of the ramp is greater than the diameter of the test coin 1, and the height *h* from the base of the ramp to the

centre of the coils is such that even the smallest coin covers the coil completely. In accordance with a preferred embodiment, l=40 mm, h=13 mm and the angle α of inclination of the ramp 2 is α = 15 degrees. D is the outside diameter of a coin 1, and d is the diameter of the centre of a two-colour coin.

[0057] In accordance with a second embodiment of the invention, not shown, the distance l is less than the diameter of the test coin, the method of the invention being equally applicable in such case, and the operation of the pertinent apparatus correct.

[0058] Figure 2 is a top plan view of the assembly of figure 1, in which s_1 and s_2 are the face to face distances between the coin 1 and the coils, T is the thickness of the coin 1 and e is the distance of separation between two coils, specifically e=3.8mm.

[0059] Figure 3 shows a simplified schematic of the electronics of an apparatus of the invention, in which can be seen the first pair of coils 3-3' and the second pair of coils 4-4' in a bridge configuration. For each pair of coils, the two coils of a same pair of coils are situated in opposite arms of the bridge. According to the embodiment shown in figures 1-3, the two coils 3-3' of opposing arms of the bridge are connected in such a manner that the magnetic fields add, and the other two coils 4-4' are connected in such a manner that the magnetic fields they produce subtract, the pair of coils 3-3' in which the magnetic fields add being situated in first place, as the coin falls, on the inlet ramp 2, and the pair of coils 4-4' in which their magnetic fields subtract in second place on the inlet ramp 2. Another embodiment possible, not shown, is the reversal of the position of the two pairs of coils on the inlet ramp 2, the pair of coils 4-4' in which the fields subtract being situated in first place as the coin falls, on the inlet ramp 2, and the pair of coils 3-3' in which their magnetic fields add in second place. The operation in this case is similar to that illustrated in figures 1.3.

[0060] The bridge is supplied with a voltage which is the sum of three alternating voltages at frequencies f_1, f_2 and f_3. The three measurement frequencies employed are: f_1 = 2.441 kHz, f_2 = 78.125 kHz and f_3 = 1.25 MHz.

[0061] The voltage of the full bridge, across P6 and P5, and the voltage of the half bridge, on P6 is obtained for each of the frequencies with synchronous demodulators that obtain the components of the signals both in phase and those 90 degrees out of phase with respect to the corresponding alternating voltages that feed the bridge, thereby obtaining a total of eight signals for the pair of coils 3-3' in which the fields are added and a further eight for the pair of coils in which the fields are subtracted. The variations in the signal 90 degrees out of phase (imaginary component) correspond to the changes in the inductive component dL and those of the in-phase signal (real component) with the changes in the resistive component dR.

[0062] All these signals, in a subsequent stage shall be processed according to known techniques, in order to obtain values of parameters representative of the coin under examination. Once said values have been calculated, they shall be compared with those of valid pieces, in order to proceed to their acceptance or rejection.

[0063] For the purpose of measuring all the parameters that are required for identifying the coins, the two pairs of coils are of reduced dimensions and are mounted in two housings on the walls of inlet ramp 2, as is shown in figures 1 and 2. Coin 1 rolls between the coils of the two pairs changing, in this manner, their impedances.

[0064] As already stated, the operation is independent of the position of the two pairs of coils 3-3' and 4-4' on inlet ramp 2. The axis of the coils is, in both pairs, perpendicular to the surface of the coin, but the sense or orientation of the winding is different; in the pair of coils 3-3', both coils are wound in the same sense and the axis of the coil is perpendicular to the surface of the coin. In the pair of coils 4-4', both coils are wound either in opposite senses with the axis of the coil pointing perpendicularly to the surface of the coin or the coils are wound in the same sense with the axis of the coil lying parallel to the surface of the coin.

[0065] Moreover the real and imaginary components are measured of the half-bridge voltage, which permits the lateral position or lift-off of the coin to be measured.

[0066] Moreover, the systems permits measurement of the velocity and the frictional effect in order to take them into account during the processing of the dimensional parameters of the coin.

[0067] The electronics related with the coils comprise a 40 MHz oscillator, a divider, mixers and amplifiers. The bridge is fed simultaneously with the three frequencies f_1, f_2 and f_3 which are obtained by means of a 40 MHz crystal oscillator and a divider. The divider is in a single-chip programmable logic circuit. This circuit also supplies the in-phase and 90 degrees out of phase reference signals for the mixers and also a timing signal for the analogue-to-digital conversion, necessary for the acquisition of the different signals.

Examples of the signals obtained with the method and apparatus of the present invention

[0068] In order to demonstrate the effectiveness of the method of the present invention, the results are shown and discussed of the measurements which were obtained using the apparatus described in the figures 1-3, with some European coins.

[0069] The signals dL and dR are shown in figures 4-18. In the figures, the signals from the pair of coils 3-3' are given in the interval of time from 0 to 0.1s and the signals from the pair of coils 4-4' are given approximately between 0.1 and 0.2s depending on the velocity and size of the coin.

[0070] Figures 4 to 11 show an example of the signals which are obtained with the method and apparatus of the invention for a brass coin with a diameter of 24.75 mm. The signals from the pair of coils 3-3' are given in the interval of time from 0.02 to 0.07s and the signals from the pair of coils 4-4' are given approximately between 0.07 and 0.11s.

[0071] Figure 12 shows the derivative of the signal dL at the one frequency of 1.25 MHz of figure 6 multiplied by 15, that is 15*ΔΔL. As already explained, this signal is employed for calculating the times t_1, t_2 , t_3 that intervene in the equation (2) for calculation of the diameter D of a coin.

[0072] Figure 13 shows the result from measuring ΔΔL obtained with the present apparatus for a two-colour coin with Magnimat centre, which is the signal which is employed for calculating the times t_4, t_5 that intervene in the equation (4) for calculation of the diameter d of the centre of a two-colour coin.

[0073] Figures 14 and 15 show the signals obtained with the method and apparatus of the invention for a British one penny piece with Copper coating, whilst figures 16 and 17 show the signals for a British penny piece when the Copper coating has been removed. These measurements illustrate the quality with which the present method can distinguish between a genuine steel coin with a Copper coating and a counterfeit coin without the coating. There are various highly distinctive characteristics by means of which the two coins can be distinguished from each other: it can be detected easily that the steel base of both coins is magnetic from the signal dL(2K441). The signal dL(78K125), is located on the side of the eddy current of the Copper-coated coin, whilst dL(78K125) of the coin without Copper coating is slightly on the magnetic side. The signal in the pair of coils 4-4' (dL1M25) of the coin without Copper coating is practically zero whilst in a coated coin it is on the side of the eddy current. As is to be expected, dR(1M25) is considerably less in the coated coin than in the uncoated counterfeit coin, both in the pair of coils 3-3' and in the pair of coils 4-4'. In brief, the characteristics found from the magnetic measurements are: diameter, thickness, magnetic and electrical properties of the steel and of the Copper coating. The parameter dL(2K441) is always negative in these coins, since the base steel is magnetic. The value of the parameter dR(1M25) is low due to the high electrical conductivity of the Copper coating.

[0074] Figures 18 and 19 show the signals obtained with the method and apparatus of the invention for a 5DEM coin which has a thin internal magnetic layer of Ni between the non-magnetic CuNi, and figures 20 and 21 show the signals obtained with the method and apparatus of the invention for a British coin of ten pence, all of which is non-magnetic CuNi. Consequently the dR signals of these coins are virtually identical. Likewise dL(78K125) and dL(1M25) are not distinguishable from each other. However the signals dL(2K441) show clearly that the 5DEM coin has an internal magnetic layer which the British ten pence coin does not.

[0075] Figures 22 and 23 show the signals obtained with the method and apparatus of the invention for a 5FF coin, which differs from the 5DEM coin in that the magnetic layer in the French five-franc coin is on the surface. This is revealed in the signals in two clearly different ways: first, the signal dR(1M25) of the 5FF coin is greater (by a factor of 1.6) than that of the 5DEM coin. Second, the signal dL(78K125) from the pair of coils 4-4' for the 5FF coin shows that its surface is of magnetic metal, whilst same signal for the 5DEM coin is on the side of the eddy current. This is due to the fact that in the 5DEM coin the magnetic field at 78.125 kHz of the pair of coils 4-4' does not penetrate to the Ni magnetic layer. In brief, the parameter dL(78K125) of the pair of coils 3-3' is positive for both coins but is, in some respect, lower for the 5FF coin than for the 5DEM coin. The parameter dL(78K125) of the pair of coils 4-4' is small but positive for the 5DEM coin, whilst it is clearly negative for that of 5FF.

[0076] Figures 24 and 25 show the signals obtained with the method and apparatus of the invention for a 10SEK coin, a single layer Nordic gold piece, which is not magnetic. Consequently in these coins, only the eddy current effects can be observed. This signifies that the parameters dL(2K441) and dL(78K125) are both positive. The parameters dL (2K441) and dR(2K441) are small. As well as measuring the magnitude of the parameters and detecting that they are on the eddy current side, the diameter and thickness measurements must be employed to identify these coins.

[0077] Figures 26 and 27 show the signals obtained with the method and apparatus of the invention for a two-colour coin with Magnimat centre, whilst the ring is non-magnetic. From the signal dL(2K441) of the pair of coils 4-4' and from the signal dL(78K125) from the pair of coils 3-3', it is possible to detect clearly that the coin under examination is a two-colour coin. The data from these signals can be employed to determine the diameter of the inside part of the coin. The parameter dL(2K441) is zero for the pair of coils 3-3', whilst it is clearly negative for the pair of coils 4-4'. The parameter dL(78K125) is positive both for the pair of coils 3-3' and for the pair of coils 4-4', but of lower value in the latter case.

Claims

1. Method for obtaining the physical characteristics of coins for their identification, which consists in subjecting the coins (1) to two consecutive stages of electromagnetic measurement, defined by a first (3-3') and a second (4-4') pairs of coils, in one of said pairs the coils are connected in such a manner that their magnetic fields are added and in the other pair the coils are connected in such a manner that their magnetic fields are subtracted, which stages provide signals which are processed in order to obtain parameters representative of the coins, **character-**

ised in that the four coils (3,3',4,4') are connected to each other according to a bridge configuration and **in that** the two pairs of coils that constitute the bridge are supplied simultaneously with at least two, and preferably three signals of different frequencies, being obtained simultaneously in each stage, on the passage of the coins (1), two signals from the full bridge for each frequency and another two signals from the half-bridge for the highest frequency, in each case one of the signals being representative of the variation in the inductive component and the other representative of the variation in the resistive component.

2. Method in accordance with claim 1, **characterised in that** the two pairs of coils that constitute the bridge are supplied simultaneously with three signals at different frequencies, around 2.5 kHz, 75 kHz and 1.2 MHz.

3. Method in accordance with claim 1, which comprises the calibration of the means through which said signals are obtained, **characterised in that** said calibration is carried out with a disc fabricated in low-loss ferrite seeking an angle of rotation β of the coordinate system in the impedance plane, for each of the frequencies, which gives a variation of the resistive component equal to zero.

4. Method in accordance with claim 1, **characterised in that** the thickness (T) of the coins is calculated by means of the expression:

$$T = e - \sqrt[N]{\frac{A}{\Delta L_{kD}}} - \sqrt[N]{\frac{A}{\Delta L_k - \Delta L_{kD}}}$$

where e is the distance separating the two coils in which their magnetic fields are added, N>0 a parameter and A another parameter, both obtained by calibration, ΔL_k the signal of the variation in the inductive component in the full bridge at the highest frequency f_k in the stage defined by the coils which add their fields, and ΔL_{kD} the signal of the variation in the inductive component in the half bridge at the highest frequency f_k in the stage defined by the coils which add their fields.

5. Method in accordance with claim 1, in which the thickness (T) of the coins is calculated by means of the expression:

$$T = e-(s_1 + s_2)$$

Where e is the distance separating the two coils in which the magnetic fields are added, and s_1 and s_2 are the distances between the two coils which add their magnetic fields and the surface of the coin, **characterised in that** s_1 and s_2 are calculated by polynomial approximation by means of the expressions:

$$s_1 = a_0 \Delta L_{kD}^{n} + a_1 \Delta L_{kD}^{n-1} + \Lambda + a_n$$

$$s_2 = b_0(\Delta L_k - \Delta L_{kD})^n + b_1(\Delta L_k - \Delta L_{kD})^{n-1} + \Lambda + b_n$$

where n is the order of polynomial approximation, a0, a1, ... an and b0, b1, ... bn are coefficients determined by calibration, ΔL_k the signal of the variation in the inductive component in the full bridge at the highest frequency f_k in the stage defined by the coils which add their fields, and ΔL_{kD} the signal of the variation in the inductive component in the half bridge at the highest frequency f_k in the stage defined by the coils which add their fields.

6. Method in accordance with claim 1, in which the diameter (D) of the coin, or the diameter (d) of the centre in the case of a two-colour coin, is calculated by means of the expression:

$$D = \frac{t_1[t_3(t_1-t_3)-t_2(t_1-t_2)]}{t_2(t_1-t_3)(t_1-t_2+t_3)} l$$

where t equal to zero at the instant at which the front edge of the coin, or of the centre for two-colour coins, enters between the first pair of coils, t1 the instant at which the rear edge of the coin, or of the centre for two-colour coins, exits from between this first pair of coils and t_2 and t_3 the instants at which the front and rear edges of the coin, or

of the centre of two-colour coins, enters and exits, respectively between the second pair of coils, and l the distance between the two pairs of coils, **characterised in that** the times t_1, t_2 and t_3 are determined by calculating the derivative of the signal of the variation of the inductive component in the full bridge, at the highest frequency for single-colour coins and, for two-colour coins, at the lowest frequency in the case of using the pair of coils in which the fields are subtracted, and at the intermediate frequency in the case of using the pair of coils in which the fields are added, and their subsequent adapting to parabolas on maxima and minima.

7. Method in accordance with claims 1 and 2, **characterised in that** for two-colour coins, the diameter (d) of the centre is obtained by means of the expression:

$$d = (t_5 - t_4)\left[v_0 + \frac{1}{3}g(t_5 + t_4)(\sin\alpha - \eta)\right]$$

where v_0 is the velocity at time t=0 at which the front edge of the coin enters between one of the pairs of coils, g is the acceleration due to gravity, α is the angle that the inlet ramp forms with the horizontal, η is the coefficient of friction, and t_4 and t_5 are the times at which the entry and exit, respectively, of the centre of the two-colour coin are detected in one of the two measurement stages, the signal of variation of the inductive component at the lowest being used in the case of using the pair of coils in which their fields are subtracted, and the signal of variation in the inductive component at the intermediate being used in the case of using the pair of coils in which their fields are added.

8. Method in accordance with claim 1, **characterised in that** taken as representative parameters of the electromagnetic characteristics of the coins are the non-dimensional values $r_1 = \Delta R_1/(\omega_k \Delta L_k)$, $r_2 = \Delta R_2/(\omega_k \Delta L_k)$, $r_i = \Delta R_i/(\omega_k \Delta L_k)$, $l_1 = \Delta L_1/\Delta L_k$, $l_2 = \Delta L_2/\Delta L_k$, $l_i = \Delta L_i/\Delta L_k$, where ΔR_1, ΔR_2, Δr_i, ΔL_1, ΔL_2, ΔL_i are variations in the resistive component and in the inductive component in the full bridge on the passage of the coins through either of the two measuring stages, for each frequency f =1, 2, ...l, ...k, $\omega_k = 2\Pi f_k$ where f_k is the maximum working frequency.

9. Method in accordance with claim 1, **characterised in that**, at each one of the frequencies, the variations undergone in each of the two measuring stages are extracted, both in the real part and the imaginary part, by means of synchronous demodulators.

10. Apparatus for obtaining physical characteristics of coins for their identification, which comprises two pairs of inductive coils, the coils in each pair being disposed opposite each other, situated on opposing sides of a coin inlet ramp, at the same height with respect to said ramp, **characterised in that** the four coils are connected in a bridge configuration, the opposing coils of each pair being connected to opposite arms of the bridge and in such a manner that in one of the pairs of coils their magnetic fields are added, whilst in the other they are subtracted, all the coils being fed simultaneously from a generator which produces at least, two first signals at different frequencies which supply the bridge, and at least, two second signals, 90 degrees out of phase with respect to the first signals.

11. Apparatus in accordance with claim 10, **characterised in that** it comprises synchronous demodulators for extracting at each one of the frequencies, the variations undergone in each of the two measuring stages during the passage of the coin, making use of the first signals for obtaining the variations of the resistive component, and making use of the second signals for obtaining the variations of the inductive component.

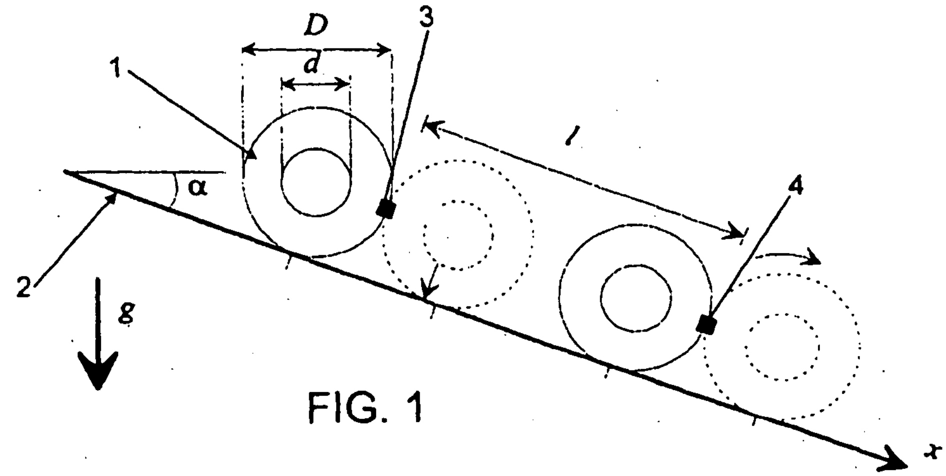


FIG. 1

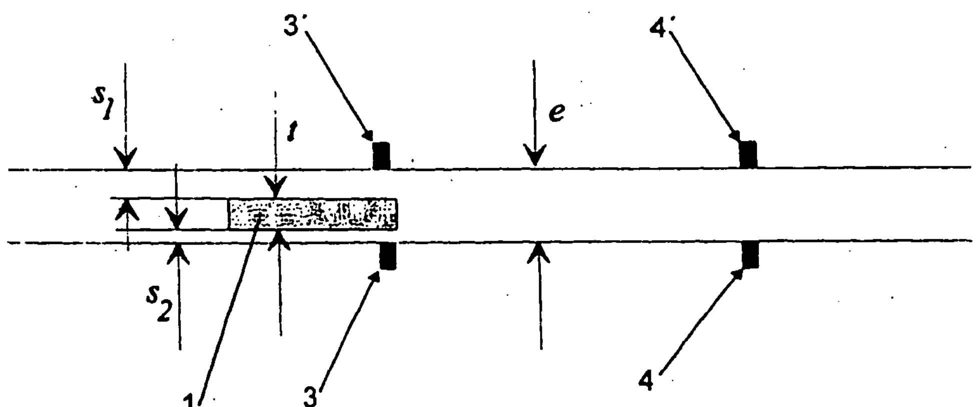


FIG. 2

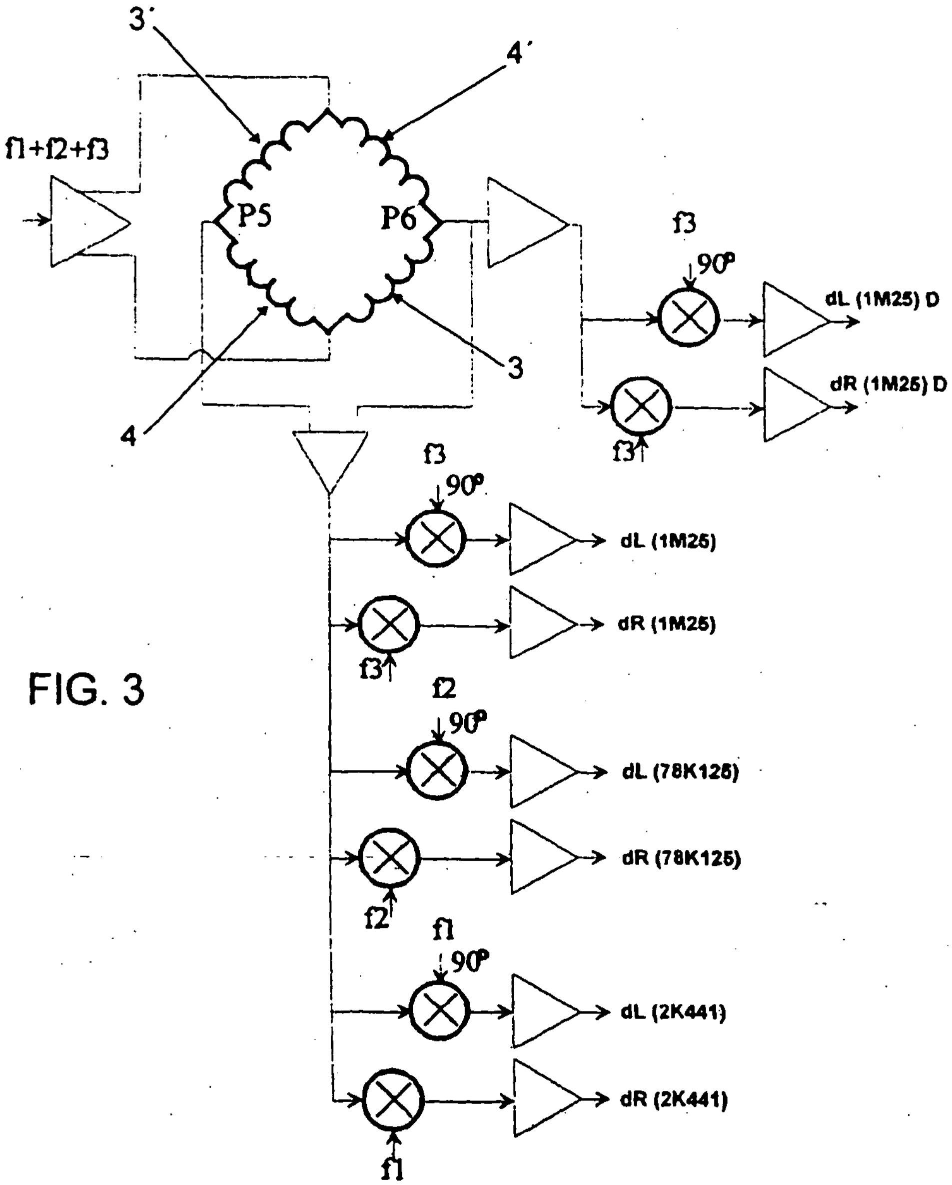

3´
4´
f1+f2+f3
P5
P6
3
4
f3
90°
dL (1M25) D
dR (1M25) D
f3
f3
90°
dL (1M25)
dR (1M25)
f3
f2
90°
dL (78K125)
dR (78K125)
f2
f1
90°
dL (2K441)
dR (2K441)
f1

FIG. 3

FIG. 4

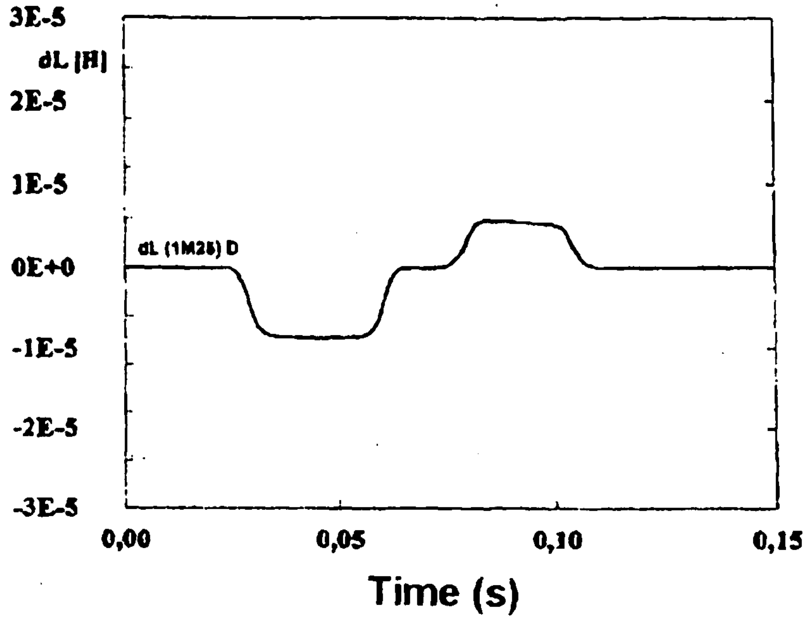

3E-5
dL [H]
2E-5
1E-5
dL (1M25) D
0E+0
-1E-5
-2E-5
-3E-5
0,00
0,05
0,10
0,15
Time (s)

FIG. 5

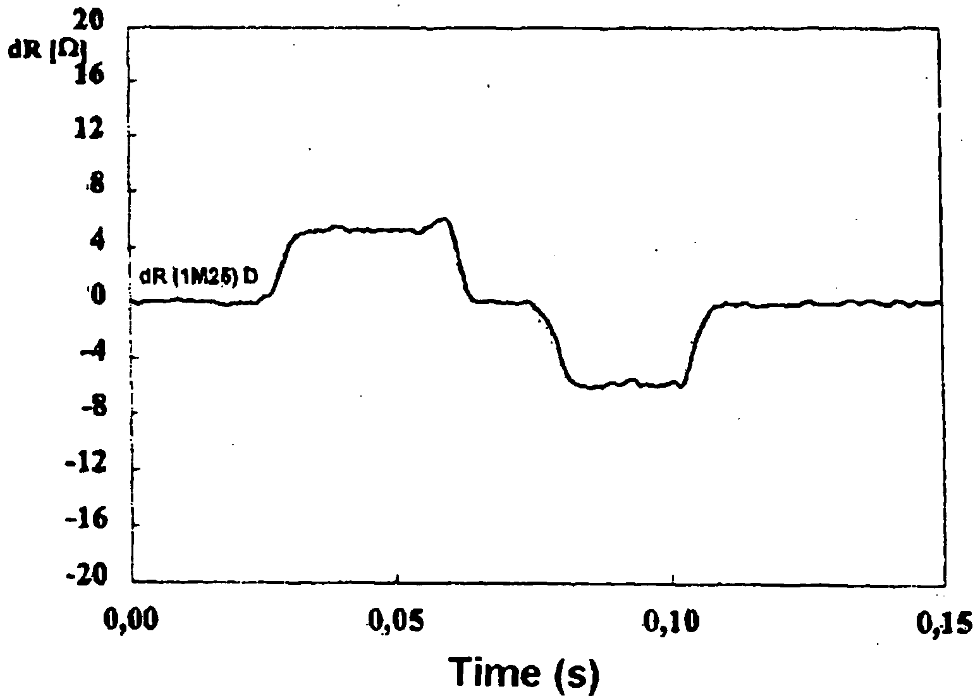

20
dR [Ω]
16
12
8
4
dR (1M25) D
0
-4
-8
-12
-16
-20
0,00
0,05
0,10
0,15
Time (s)

FIG. 6

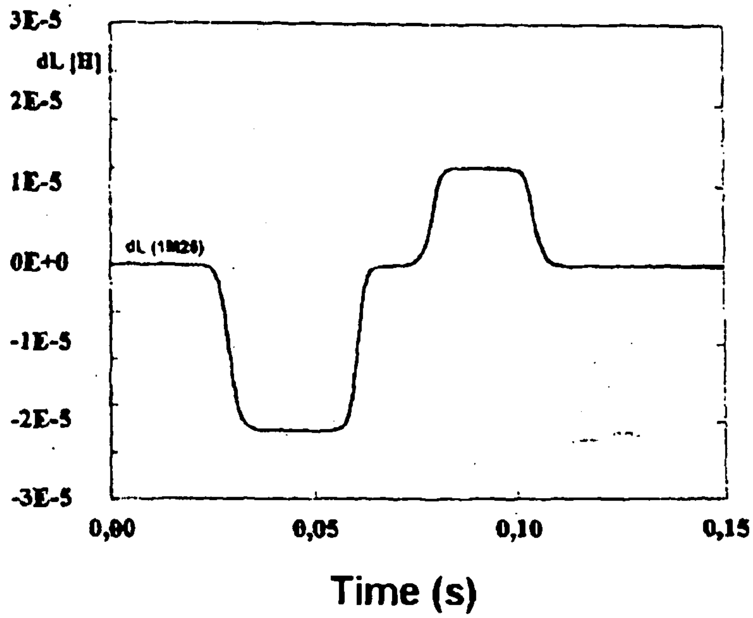

3E-5
dL [H]
2E-5
1E-5
dL (1M25)
0E+0
-1E-5
-2E-5
-3E-5
0,00
0,05
0,10
0,15
Time (s)

FIG. 7

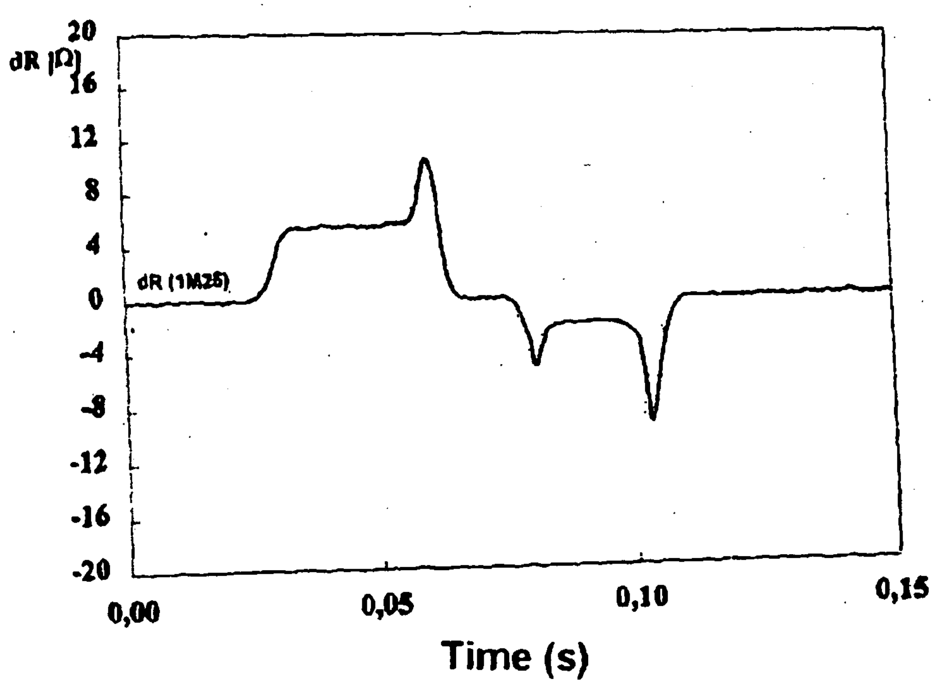

20
dR [Ω]
16
12
8
4
dR (1M25)
0
-4
-8
-12
-16
-20
0,00
0,05
0,10
0,15
Time (s)

FIG. 8

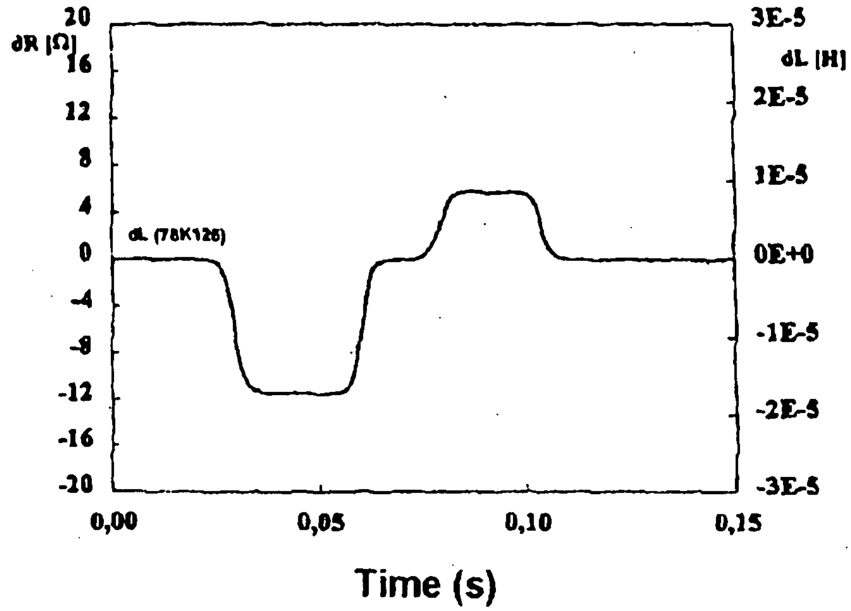

dR [Ω]
20
16
12
8
4
0
-4
-8
-12
-16
-20
dL (78K126)
3E-5
dL [H]
2E-5
1E-5
0E+0
-1E-5
-2E-5
-3E-5
0,00
0,05
0,10
0,15
Time (s)

FIG. 9

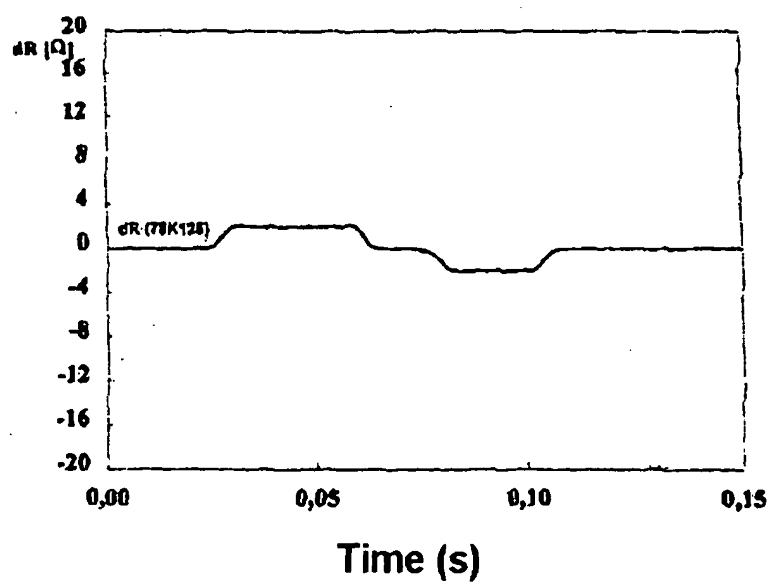

dR [Ω]
20
16
12
8
4
0
-4
-8
-12
-16
-20
dR (78K125)
0,00
0,05
0,10
0,15
Time (s)

FIG. 10

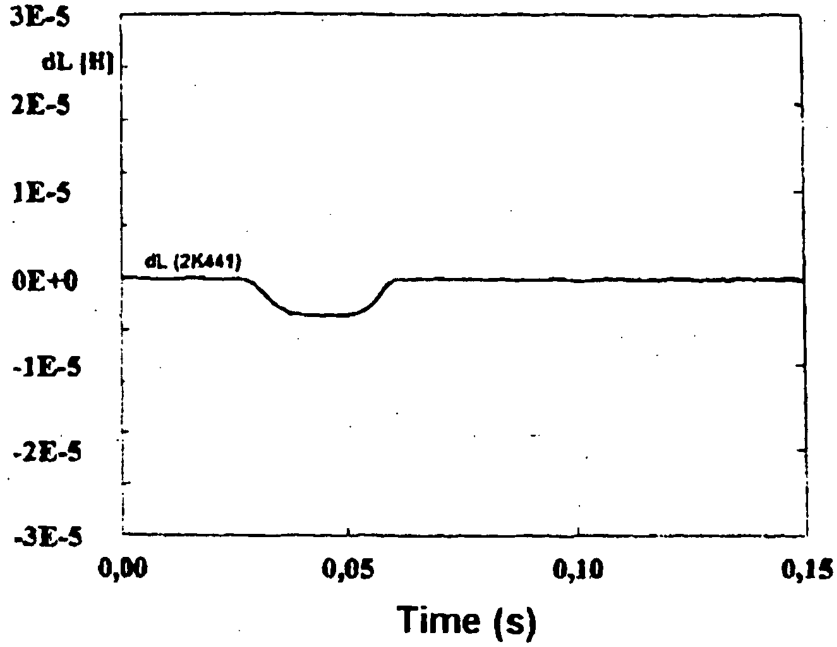

3E-5
dL [H]
2E-5
1E-5
0E+0
-1E-5
-2E-5
-3E-5
dL (2K441)
0,00
0,05
0,10
0,15
Time (s)

FIG. 11

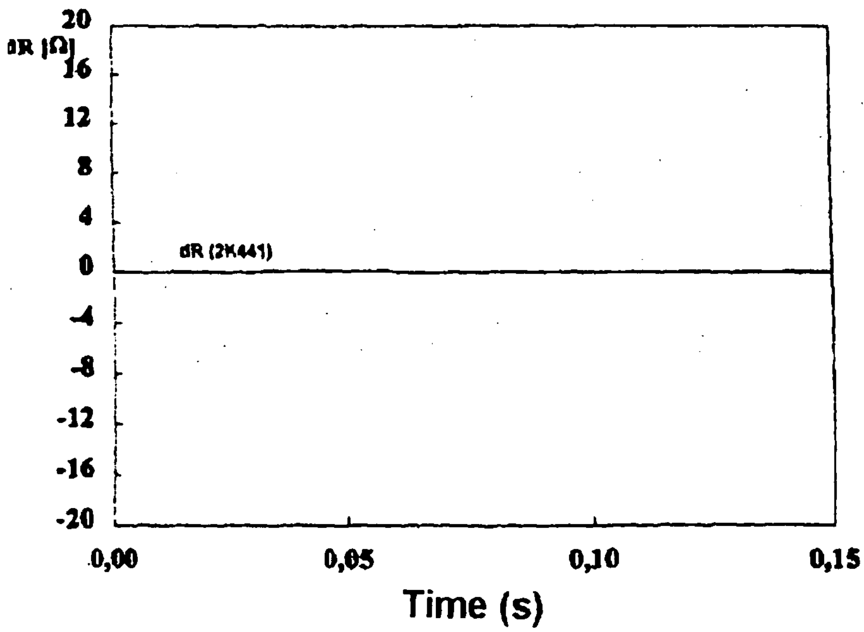

20
dR [Ω]
16
12
8
4
0
-4
-8
-12
-16
-20
dR (2K441)
0,00
0,05
0,10
0,15
Time (s)

FIG. 12

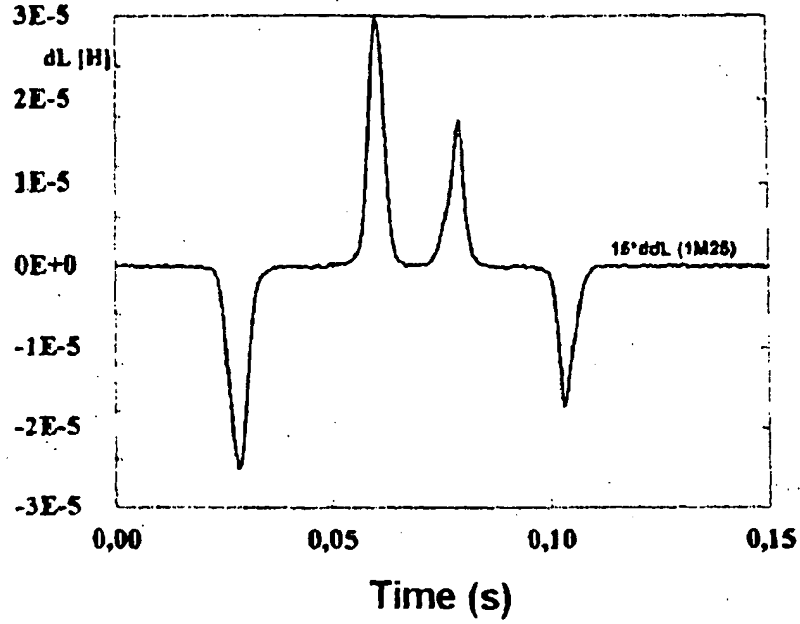

3E-5
dL [H]
2E-5
1E-5
0E+0
-1E-5
-2E-5
-3E-5
15*ddL (1M25)
0,00
0,05
0,10
0,15
Time (s)

FIG. 13

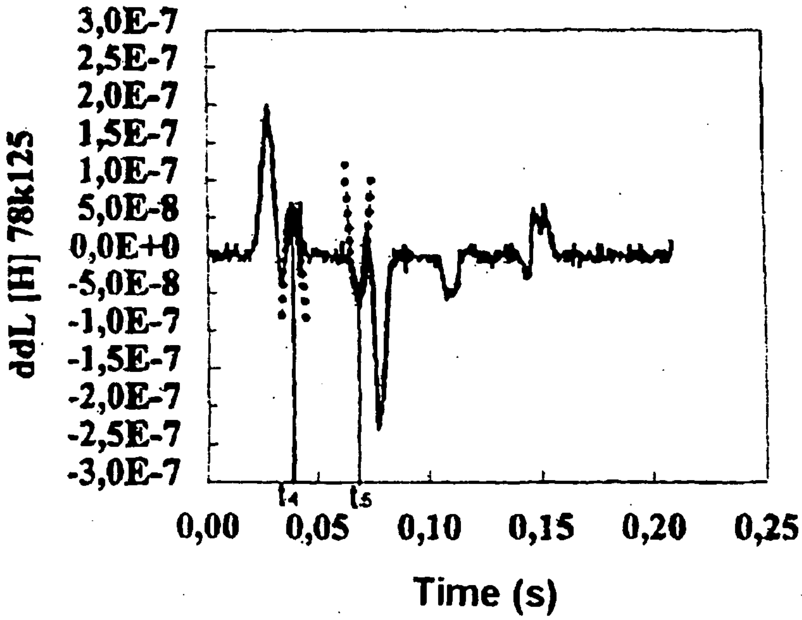

3,0E-7
2,5E-7
2,0E-7
1,5E-7
1,0E-7
5,0E-8
0,0E+0
-5,0E-8
-1,0E-7
-1,5E-7
-2,0E-7
-2,5E-7
-3,0E-7
ddL [H] 78k125
t4
t5
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 14

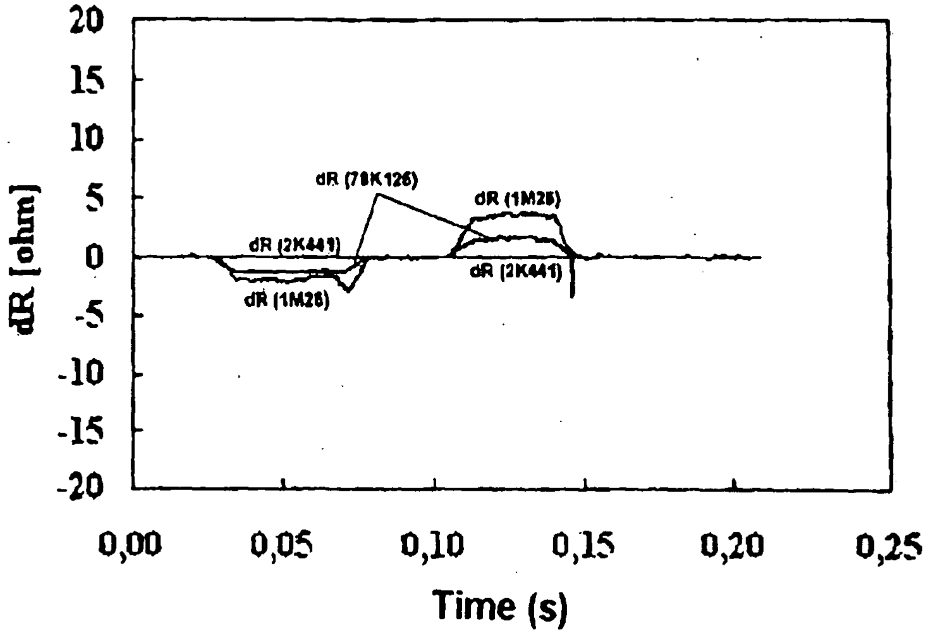

dR [ohm]
20
15
10
5
0
-5
-10
-15
-20
dR (78K126)
dR (1M26)
dR (2K441)
dR (2K441)
dR (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 15

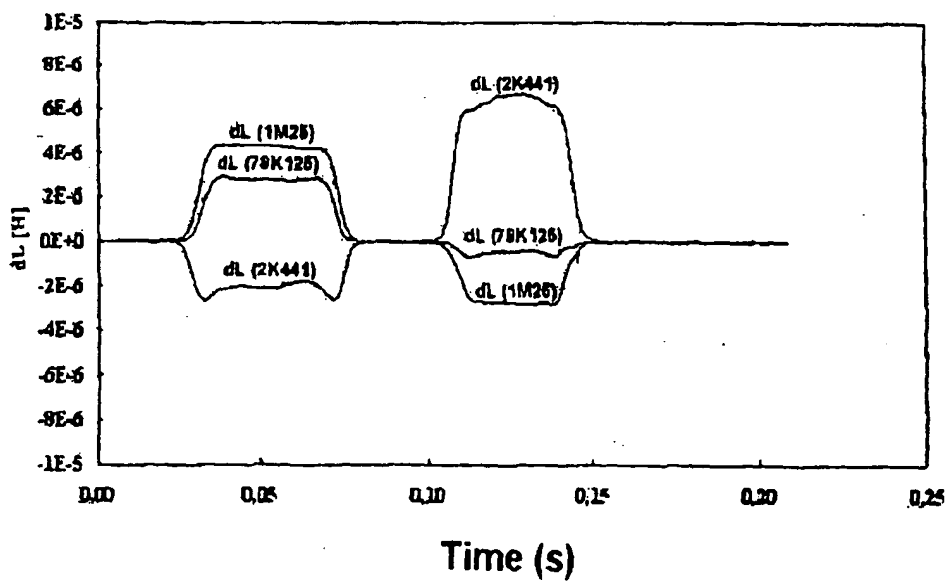

dL [H]
1E-5
8E-6
6E-6
4E-6
2E-6
0E+0
-2E-6
-4E-6
-6E-6
-8E-6
-1E-5
dL (1M26)
dL (78K126)
dL (2K441)
dL (2K441)
dL (78K126)
dL (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 16

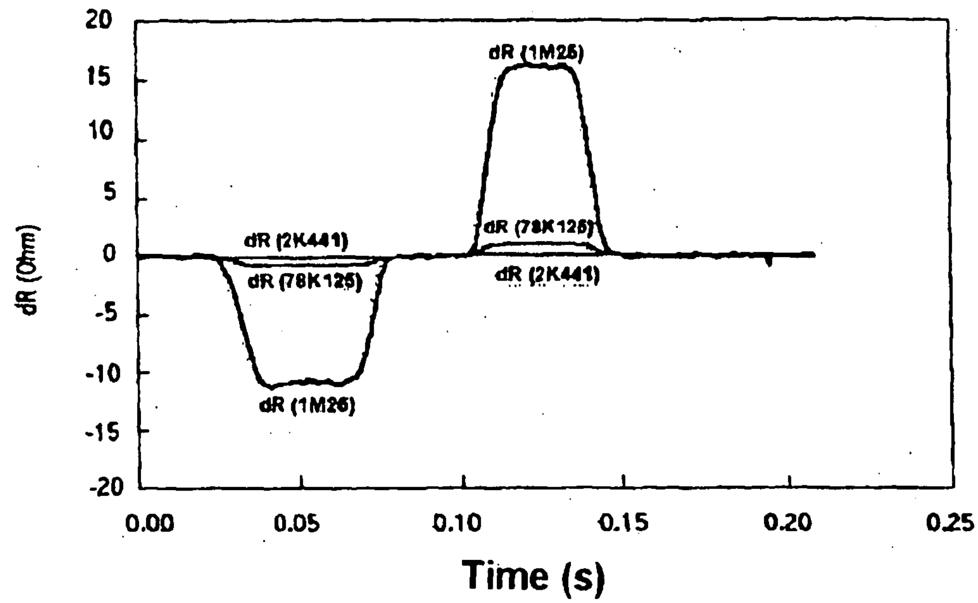

dR (1M26)
dR (78K126)
dR (2K441)
dR (2K441)
dR (78K126)
dR (1M26)
dR (Ohm)
20
15
10
5
0
-5
-10
-15
-20
0.00
0.05
0.10
0.15
0.20
0.25
Time (s)

FIG. 17

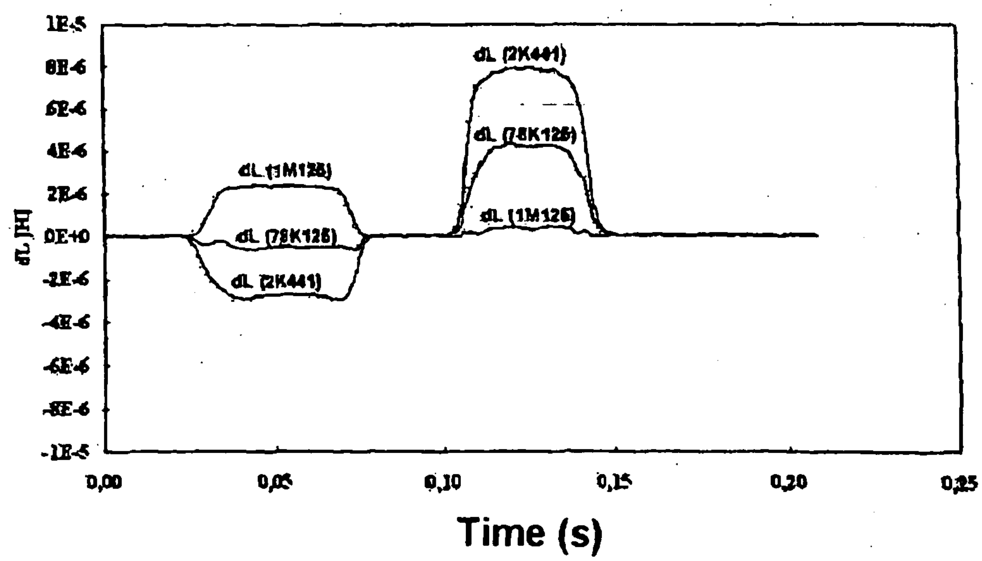

dL (2K441)
dL (78K126)
dL (1M126)
dL (1M126)
dL (78K126)
dL (2K441)
dL [H]
Time (s)

FIG. 18

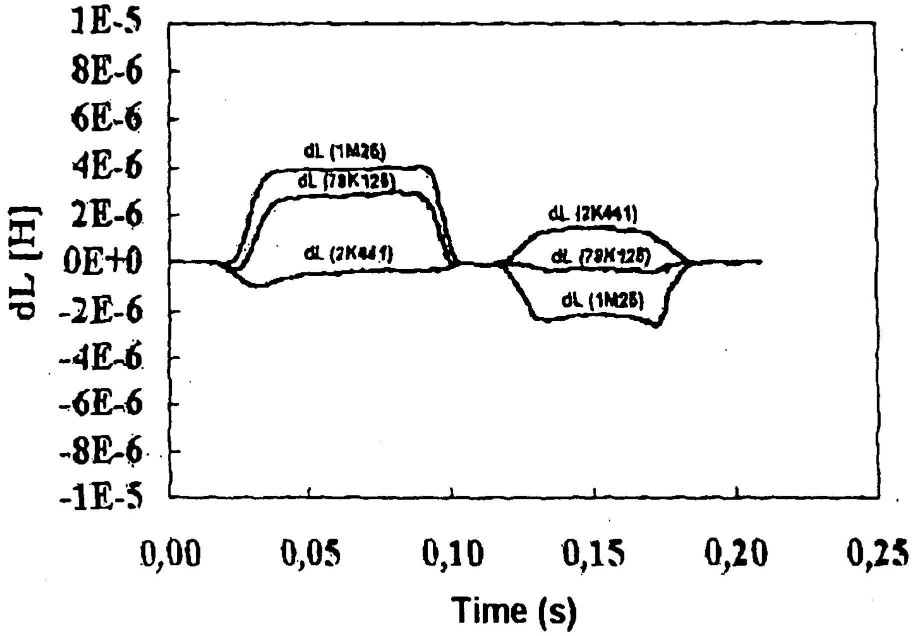

dL [H]
1E-5
8E-6
6E-6
4E-6
2E-6
0E+0
-2E-6
-4E-6
-6E-6
-8E-6
-1E-5
dL (1M26)
dL (78K128)
dL (2K441)
dL (2K441)
dL (78K128)
dL (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 19

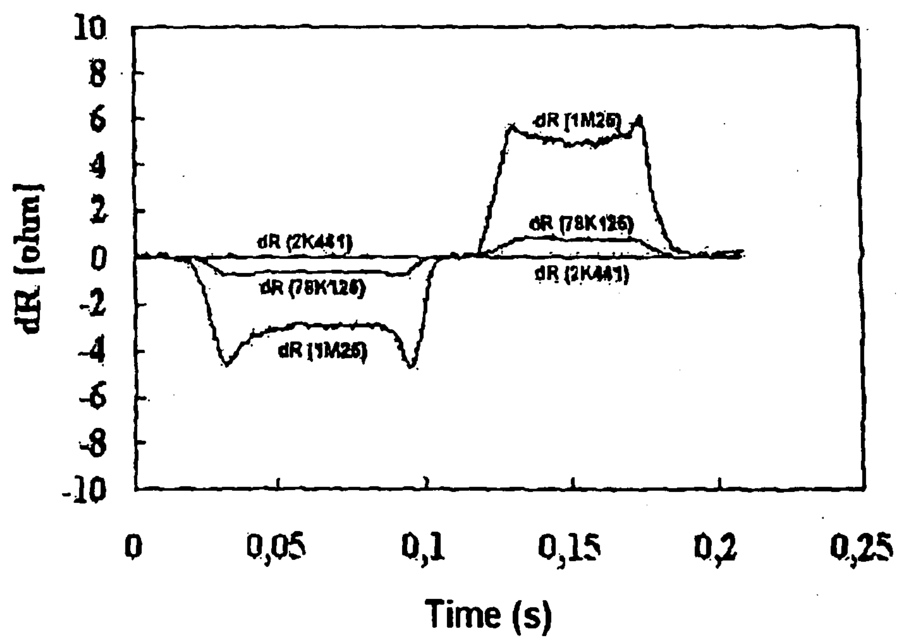

dR [ohm]
10
8
6
4
2
0
-2
-4
-6
-8
-10
dR (1M26)
dR (78K126)
dR (2K441)
dR (2K441)
dR (78K126)
dR (1M26)
0
0,05
0,1
0,15
0,2
0,25
Time (s)

FIG. 20

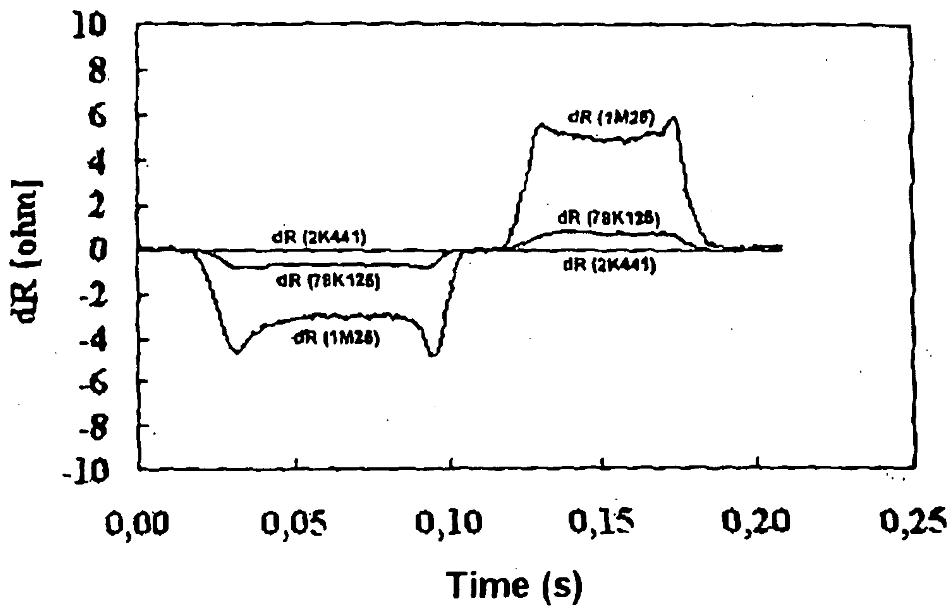

10
8
6
4
2
0
-2
-4
-6
-8
-10
dR [ohm]
dR (1M26)
dR (78K126)
dR (2K441)
dR (2K441)
dR (78K126)
dR (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 21

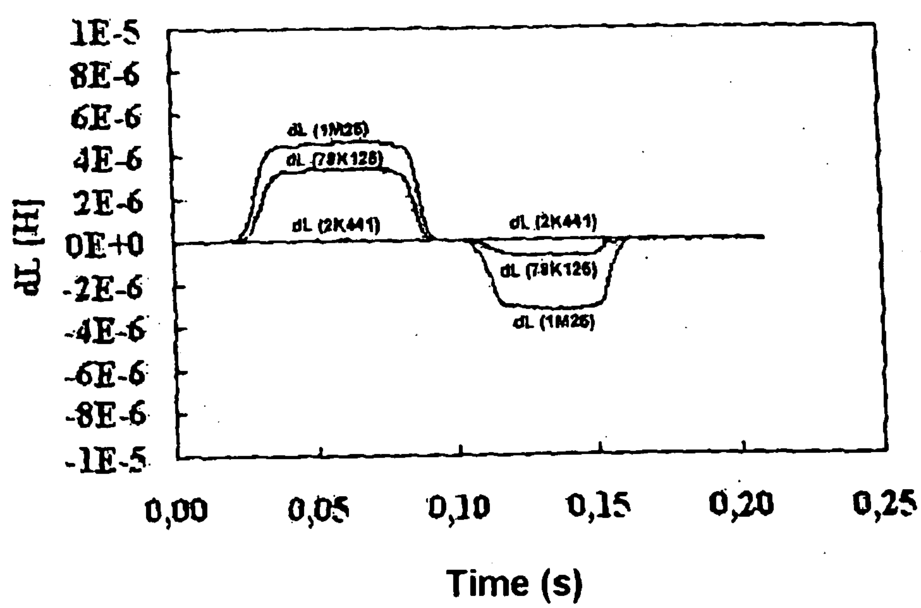

1E-5
8E-6
6E-6
4E-6
2E-6
0E+0
-2E-6
-4E-6
-6E-6
-8E-6
-1E-5
dL [H]
dL (1M26)
dL (78K126)
dL (2K441)
dL (2K441)
dL (78K126)
dL (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 22

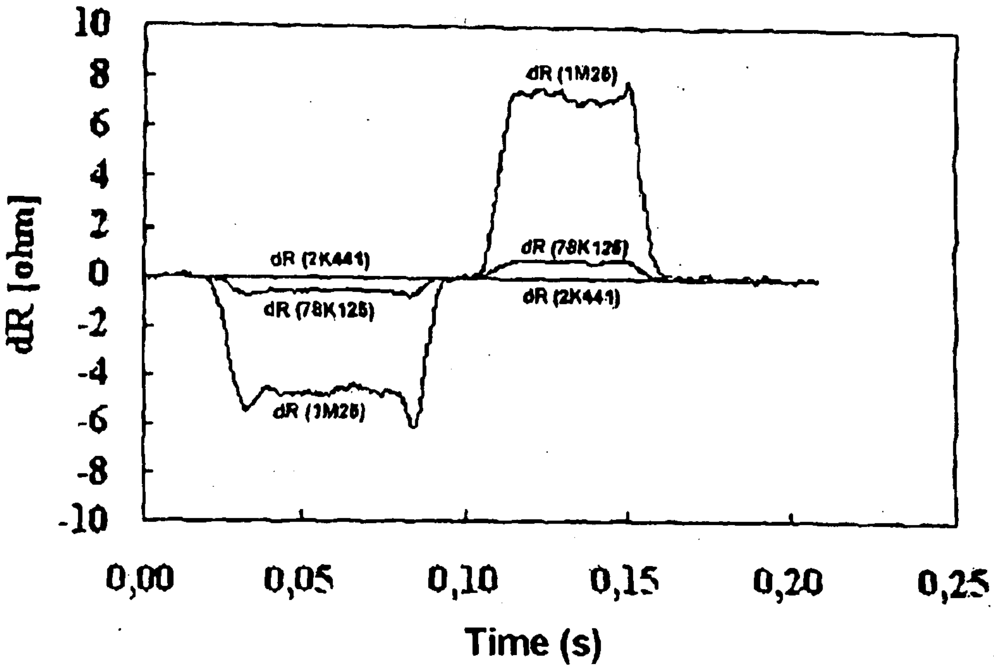

dR [ohm]
10
8
6
4
2
0
-2
-4
-6
-8
-10
dR (1M26)
dR (78K126)
dR (2K441)
dR (78K126)
dR (2K441)
dR (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 23

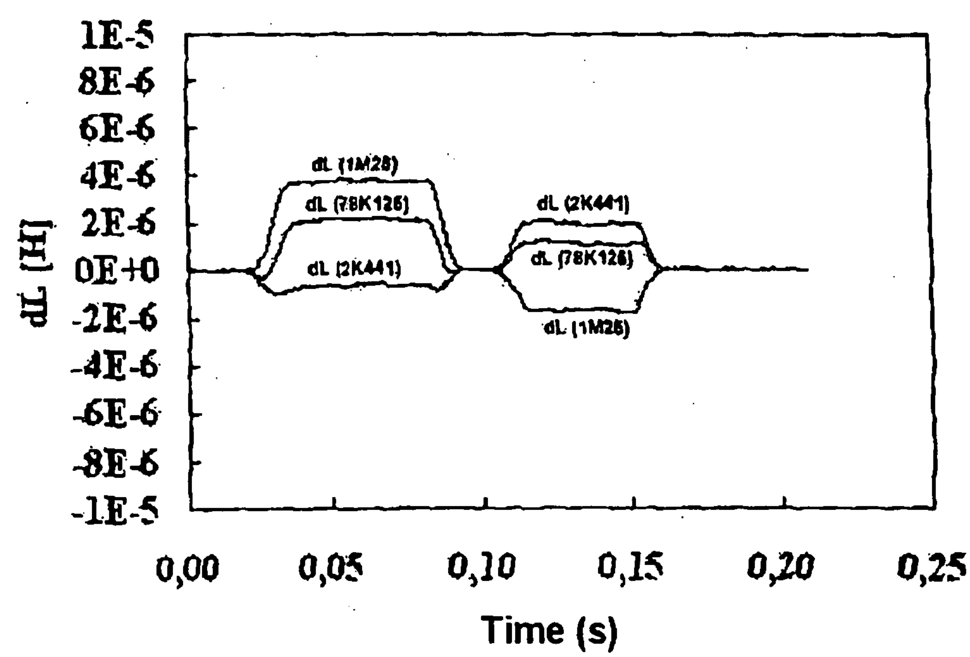

dL [H]
1E-5
8E-6
6E-6
4E-6
2E-6
0E+0
-2E-6
-4E-6
-6E-6
-8E-6
-1E-5
dL (1M26)
dL (78K126)
dL (2K441)
dL (2K441)
dL (78K126)
dL (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 24

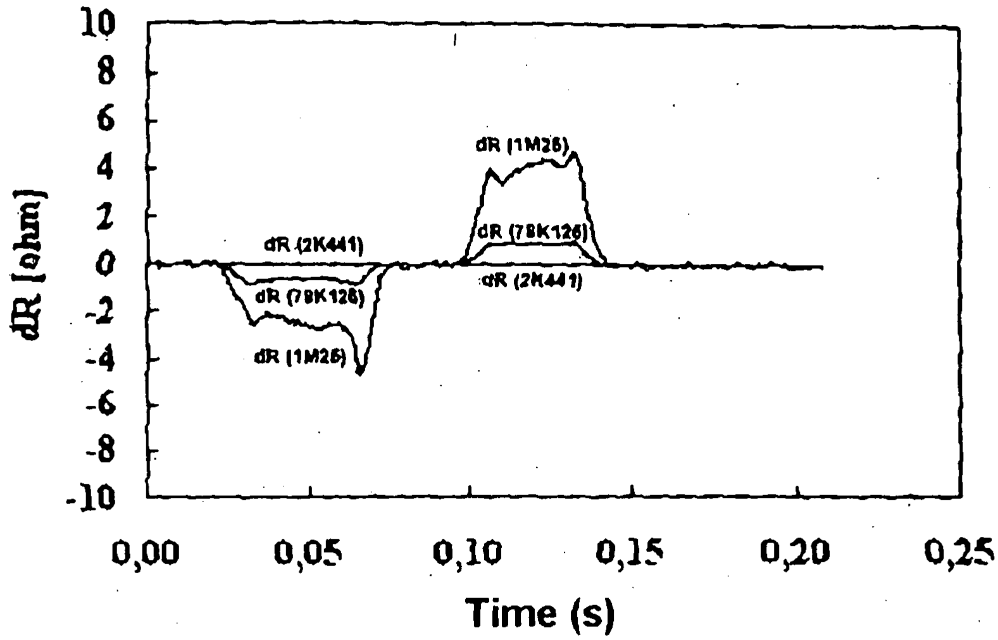

10
8
6
4
2
0
-2
-4
-6
-8
-10
dR [ohm]
dR (1M26)
dR (78K126)
dR (2K441)
dR (2K441)
dR (78K126)
dR (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 25

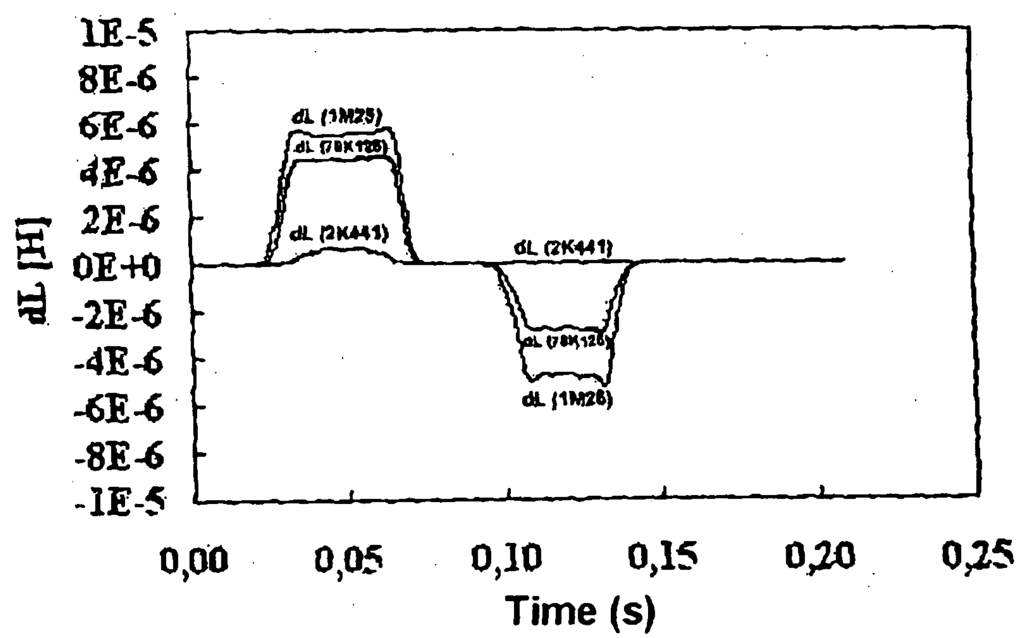

1E-5
8E-6
6E-6
4E-6
2E-6
0E+0
-2E-6
-4E-6
-6E-6
-8E-6
-1E-5
dL [H]
dL (1M26)
dL (78K126)
dL (2K441)
dL (2K441)
dL (78K126)
dL (1M26)
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 26

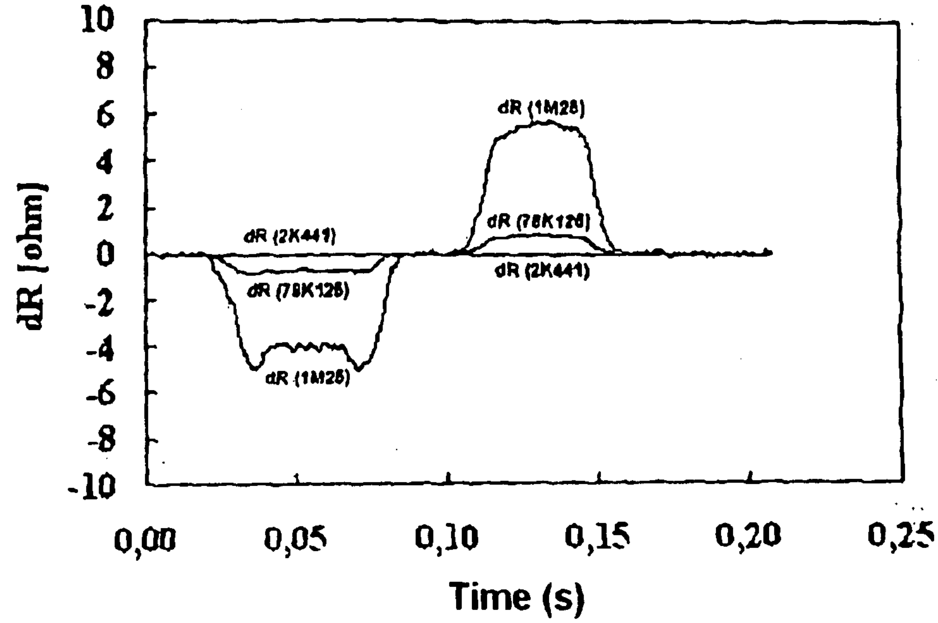
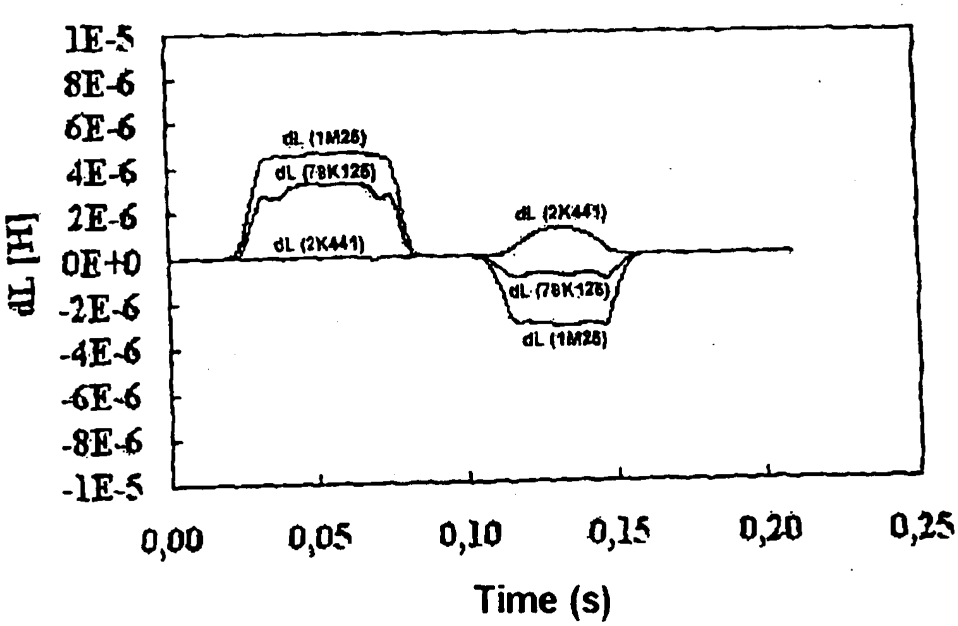

dR (1M28)
dR (78K128)
dR (2K441)
dR (2K441)
dR (78K128)
dR (1M28)
10
8
6
4
2
0
-2
-4
-6
-8
-10
dR [ohm]
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)

FIG. 27


dL (1M28)
dL (78K128)
dL (2K441)
dL (2K441)
dL (78K128)
dL (1M28)
1E-5
8E-6
6E-6
4E-6
2E-6
0E+0
-2E-6
-4E-6
-6E-6
-8E-6
-1E-5
dL [H]
0,00
0,05
0,10
0,15
0,20
0,25
Time (s)